SEARCH FOR HEAVY ANTINUCLEI IN THE COSMIC RADIATION

Niels Lund and Miriam Rotenberg
The Copenhagen-Saclay HEAO Collaboration
Danish Space Research Institute, Lundtoftevej 7, DK-2800 Lyngby

Introduction

The cosmic radiation is one of the few channels through which the existence of significant amounts of antimatter in the Universe may be demonstrated. Such a finding would be of fundamental importance for cosmology as well as for particle physics.

The data from the Danish-French Cosmic Ray Spectrometer on the HEAO-3 satellite offers an opportunity to search for heavy antinuclei, since all the relevant parameters (charge, velocity, arrival direction, and satellite position at the time of arrival) are measured for each recorded nucleus.

Instrumentation and initial data selection

The HEAO-3 instrument is described in detail in (3). The charge and velocity of each particle is determined from the signals produced in a stack of five Cerenkov counters.

The consistency of the signals are used to check for particles undergoing nuclear interactions while traversing the instrument. For this investigation, however, the consistency requirements have been relaxed somewhat from the values used generally, in order not to reject antinuclei, which are expected to yield signals differing slightly from those of their positive counterparts.

The particle velocity is determined from a fit to the Cerenkov signals. We use a routine which determines not only the best fit velocity, but also the lower and upper bounds for a velocity interval outside which the true values should only lie in one case out of 10^5.

Particles with inconsistent values of the velocity signals have been rejected.

The present analysis is limited to elements heavier than fluorine since the reliability of the time-of-flight system has been found to degrade somewhat for lighter elements.

Pilot runs showed that the number of particles with zenith angles less than 90° which could be assigned a unique charge is quite small. Consequently we restrict the data base to particles with zenith angles greater than 90°.

Trajectory tracings

Before beginning the trajectory tracings the acceptable velocity range mentioned above is converted to a rigidity interval by using a very wide range of possible isotopic masses for each element. This procedure takes into account the possibility that a short lived fragment produced in the atmosphere may follow a different trajectory than the ones available to the stable isotopes.

The helix-method (4) is used for the trajectory tracings. The magnetic field model used is a 14. order model based on MAGSAT data (5). For each rigidity value it is checked if any of the two possible charge signs corresponds to an acceptable arrival situation. Dependent on the outcome of the tracings the particles are divided into four classes:

1) Both charge signs are possible. This class contains all events for which at least one positive rigidity and at least one negative rigidity are acceptable.

2) Only a positive sign is possible, i.e., particles for which at least one positive rigidity is acceptable and none of the negative rigidities are acceptable.

3) Only a negative sign is possible, i.e., all positive rigidities forbidden, but at least one negative is allowed.

4) Neither sign is allowed, all positive as well as negative rigidities are forbidden.

A very conservative criterion for classifying a rigidity as "forbidden" has been used. It is demanded that the corresponding trajectory intersects the solid Earth within a trajectory length of one Earth radius from the satellite position.

In order to allow for some error in the determination of the particle arrival directions, any particle which is initially in class 2, 3 or 4 is recalculated using a zenith angle diminished by 2 degrees relative to the measured value.

Results

Of the initial data set about 25% or 34070 events are classified as positive only, 15 events are negative only (antiparticle candidates) and 10 events are impossible regardless of the sign assumed. The rest, 103266 events, are consistent with either charge sign.

Details on the 25 particles of classes 3 and 4 can be found in tables 1 and 2.

Inspection of these 25 events reveals that 7 antiparticle candidates and 2 impossibles were all recorded on one single day (Nov. 11, 1979). The total set comprises data from over 400 days. We have found no satisfactory explanation for this burst of unusual trajectories. There were no signs of instrument or satellite malfunctions. A Forbush decrease occurred on this day, but we see no particular reson to connect the two events. The geomagnetic activity index was between 1 and 2+. We have noted that 8 of the 9 unusual events were recorded in the vincinity of the Sourth Atlantic Anomaly. The instrument was switched off during the passages through the Anomaly and the 8 events occurred in the first few minutes after switch on. The connection between the switching of the experiment and the peculiar events is not obvious, however, because in the total data set there are several thousand such passages without irregularities. We have therefore decided to reject all events (of all classes) recorded on this day from this work.

The remaining 8 impossible events indicate the level of background for the antiparticle search. This background may be due to inadequacies of the measured data (charge, velocity, and arrival direction for the particles) or it may arise due to inadequacies of the magnetic field model. The MAGSAT model does not describe local crust related magnetic anomalies and does not take into account magnetic disturbances which might exist at the specific time of our particle recordings.

When analyzing the geographic distribution of the remaining "impossibles", it appears that the problem lies with the magnetic field data because these particles have preferentially been detected at low geomagnetic cut-off values where magnetospheric disturbances have the largest effect. We have therefore investigated the effect of excluding data obtained at locations with geomagnetic L-values greater than 1.5. It turns out that most of the "particle" candidates remain in this selection whereas all the "antiparticle" candidates and all but one of the "impossibles" are gone. This last "impossible" event may be reasonably attributed to the uncertainty of the time-of-flight imformation. In fact, an independent analysis leads us to suspect a residual contamination at the 10^{-4} level for the time-of-flight system. We also note that all but one of the Nov. 11 events have L-values greater than 1.5.

Conclusion

Using the 22676 "positive only" events in the data selection corresponding to $L \leq 1.5$ as a measure of our "exposure factor" to heavy antinuclei and noting that no corresponding antinuclei were found we can give an upper limit (95% confidence) to the ratio of antinuclei to nuclei as 1.4×10^{-4} for particles with $|Z| > 9$. In table 3 we compare the upper limit resulting from this work with previous results of searches for heavy antimatter in the cosmic radiation. It is seen that, if one regards only antiparticles heavier than fluorine, then the present result represents a reduced upper limit over previous data. When taken together, all the available experiment data now push the upper limit for the ratio of antiparticles to particles well below 10^{-4}.

As a final remark we may stress that we have found no satisfactory explanation for the 9 unusual particle tracks seen on November 11, 1979. We would appreciate being informed of other geophysical "curiosities" which might have been observed on this date.

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TABLE 1 Antiparticle candidates

Date	GMT	Lat.	Long.	L-value	Zen.	Az.	Z	p GeV/c	4.3 σ range
791111	07 59	-43.3°	32.1°	2.51	128°	20°	10	4.13	3.74 - 4.89
791111	07 59	-43.3	32.3	2.51	123	44	14	1.58	1.52 - 1.65
791111	08 00	-43.5	37.0	2.52	135	18	13	4.66	4.19 - 5.54
791111	08 01	-43.6	39.7	2.52	107	29	19	8.02	7.40 - 9.31
791111	09 37	-43.0	27.3	2.49	119	36	14	2.16	1.98 - 2.45
791111	09 37	-42.8	28.9	2.49	129	15	14	5.38	4.66 - 6.41
791111	09 38	-42.4	31.6	2.49	122	36	14	2.11	1.94 - 2.35
791215	14 46	-43.6	74.8	3.0	105	138	10	1.17	1.14 - 1.19
800129	17 18	-38.0	133.4	2.5	109	79	13	7.22	6.70 - 8.22
800205	09 08	-43.4	-175.8	2.4	130	-63	12	2.14	1.94 - 2.48
800206	00 04	41.8	148.9	1.6	95	55	12	6.28	5.27 - 6.70
800415	02 20	-43.6	-36.4	1.63	109	46	10	3.09	2.97 - 3.28
800715	20 13	-36.8	61.2	2.2	114	52	18	7.15	6.73 - 7.90
801025	09 35	-36.5	-171.7	1.75	99	123	10	8.73	7.44 - 12.94
801031	13 38	-41.2	102.0	3.0	107	116	12	8.81	7.66 - 11.94

TABLE 2 "Impossible particles"

790930	20 57	-42.8°	104.8°	3.3	135°	-75°	12	4.30	3.89 - 5.02
791005	18 06	41.8	-71.3	3.1	119	-48	13	1.21	1.20 - 1.22
791017	17 08	-43.3	72.2	3.0	134	86	13	1.97	1.82 - 2.21
791111	10 05	16.2	116.3	1.0	146	114	16	56.36	15.4 - ∞
791111	11 22	-25.9	48.2	1.6	109	171	12	6.73	6.34 - 7.44
791208	21 04	-43.5	18.2	2.3	168	70	10	1.28	1.26 - 1.32
800628	17 08	-43.6	-176.0	2.4	147	-107	20	5.43	4.87 - 6.31
800823	00 50	-43.5	57.6	2.4	152	-54	14	2.68	2.34 - 2.97
800912	05 19	35.6	2.6	1.5	144	-79	10	16.36	10.13 - ∞
801105	06 32	38.7	-12.3	1.8	129	14	20	20.07	11.42 - ∞

TABLE 3 Searches for antinuclei

		95% confidence upper limit
Badhwar et al (1978)	$Z = 2$	1.7×10^{-4}
Smoot et al (1975)	$Z > 2$	0.8×10^{-4}
Present work	$Z > 9$	1.4×10^{-4}

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